E
378.748
POS1897.8

E378.748
POS1897.8

GIFT OF
Univ

Corliss Engine Efficiency. Comly & Galbraith '97

E 378.748
POS 1897.8

UNIVERSITY
of
PENNSYLVANIA
LIBRARIES

50 Pages.

4 June '48. Sec. of Univ. of S. Norwood

Application of Hirn's Analysis to the Hamilton Corliss Engine in the Mechanical Laboratory of University of Penna.

G. N. Comly and T. R. Galbraith.

Hirn's analysis consists in the determination of the heat losses to which the steam is subjected in its passage through the cylinder or rather it is an investigation of the interchange of heat between the steam and the cylinder walls. In fact, the iron has been shown to play a most important part in the transformations that take place within the engine. Through its agency, heat is abstracted from the steam and stored in its mass, part of it escaping out

ward into the air and remainder returning to the steam.

This method of testing is eminently practical, examining as it does the condition of the steam itself. The theory of Him is thus concisely put by Professor Unwelsh-vers-Very:-

"Between any two positions of the piston, the quantity of heat which has done external work and that which is exchanged between the metal and the steam form a sum equal to the difference between the amount of heat in the two positions, increased by the heat which may have been introduced with the new steam or diminished by that which may have left the cylinder."

It might perhaps at first thought seem that it was a severe test of cre-

duility to put forth the statement that, during the rapid motion of the piston back and forward, the walls of the cylinder could cool down. But such now is a well established fact. Although, when we know the position of the piston at cut off and compression and the laws of expansion of saturated steam, it is easy to calculate the work done by an engine, yet the result obtained is only approximate. It is true that the quantity of water in the steam which varies from moment to moment, and the continual fluctuation of pressure in the supply pipe have some influence on the changes of condition of the steam within the cylinder but from the experiments of Hirn, Le Louter, and Hallauer, it has been

conclusively proved that the walls of the cylinder are the most potent factor affecting the production of work and heat transferrences. It is with the action of the walls upon the steam and the consequent heat interchanges that Hirn's analysis is occupied.

The following is a statement of the analysis;-

Let the quality of the steam in the supply pipe be x, where x represents the percentage of steam in the mixture of steam and water. Let M pounds of steam be admitted to the cylinder per stroke. Then the heat supplied to the engine per stroke is

$$Q = M(q + xr)$$

where q is the heat of liquid and r the heat of vaporization at the pressure of the steam.

Let x_0 be the quality of the steam at the end of compression and let M_0 pounds be caught in the cylinder by compression. Then the heat retained by compression is

$$Q_0 = M_0 (q_0 + x_0 \rho_0)$$

in which ρ is the heat equivalent of the internal work.

Since, after admission there is in the cylinder $M + M_0$ pounds of steam, the heat at cut off is

$$H_1 = (M + M_0)(q_1 + x_1 \rho_1)$$

Similarly for the heat at release

$$H_2 = (M + M_0)(q_2 + x_2 \rho_2)$$

During exhaust, there are M pounds of steam forced out of the cylinder. The heat in the remaining M_0 pounds at the beginning of compression is

$$H_3 = M_0(q_3 + x_3\rho_3)$$

On the above equations the subscripts 0, 1, 2, and 3 refer to the points on the indicator diagram corresponding to the pressures of admission or end of compression, cut off, release, and beginning of compression.

These equations all involve the quantity x. Consequently before the values of the different heats can be obtained it is necessary to determine the quality of the steam at the different points. Let σ be the volume in cubic feet of one pound of water and let u be the change in volume due to its conversion into steam. Then the volume of one pound of dry steam is $u + \sigma$ and the volume of a mixture of steam and water weighing one pound is

$xu + \sigma$. Let the volume of the clearance of the engine be V_c cubic feet. Let the volume swept through by the piston up to cut off be V_1 and up to release V_2. Also let the volume at beginning of compression be $V_0 + V_3$. Then the volumes of the mixture of steam and water are

at admission $= V_0 = M_0 (x_0 u_0 + \sigma)$

at cut off $= V_0 + V_1 = (M + M_0)(x_1 u_1 + \sigma)$

at release $= V_0 + V_2 = (M + M_0)(x_2 u_2 + \sigma)$

at compression $= V_0 + V_3 = M_0 (x_3 u_3 + \sigma)$

Now in each of these four equations there are two unknown quantities, M_0 and x. If in any way we can find the quality of the steam at one point of the stroke we can compute M_0 and therefore the x at all the other points. It is difficult and in fact almost impossible to find, experimentally, with

any degree of accuracy the quality of the steam at any particular point owing to the changing condition of the steam. The only recourse is to assume it. It is safest to assume the value of x in compression. In the first place, it is known to be nearer unity than anywhere else during the stroke. For since the x at release is higher than at cut off (because of the reevaporation of the steam condensed in the earlier part of the stroke) and since the work of exhaust is done on the steam. thus increasing its heat and causing more moisture to be vaporized, it follows that the x at compression should be higher. But in the second place an error in x in the compression can only slightly affect

the final result, because the weight of steam in compression is very small compared with the total weight of steam admitted. Hallauer has proved experimentally that the error caused by the assumption that the steam in the clearance spaces is dry and saturated is within the limits of experimental errors.

Assuming then that x_3 and x_0 are unity, we have

$$M_0 = \frac{V_0 + V_3}{w_3 + \sigma} = (V_0 + V_3)\gamma_3$$

where γ_3 is the density of one cubic foot of saturated steam at the absolute pressure of the beginning of compression.

Solving for x_1 and x_2

$$x_1 = \frac{V_0 + V_1}{(M + M_0)w_1} - \frac{\sigma}{w_1}$$

$$x_2 = \frac{V_0 + V_2}{(M + M_0)w_2} - \frac{\sigma}{w_2}$$

If we represent the work under any indicator line and down to the line of perfect vacuum by W, the work in heat units is AW where A is the reciprocal of Rowlands mechanical equivalent of heat or $\frac{1}{778}$. Then if a, b, c, and d represent admission, expansion, exhaust, and compression respectively, the heat equivalent of external work

during admission is AW_a
during expansion is AW_b
during exhaust is AW_c
during compression is AW_d

Recalling now the theory of Hirn as enunciated by Dwelshauvers-Dery quoted above we are now able to write equations for the interchanges of heat. The heat which is transferred is

during admission $Q_a = Q + Q_0 - H_1 - AW_a$

during expansion $Q_b = H_1 - H_2 - AW_b$

during exhaust $Q_c = H_2 - H_3 - M q_c - G(q_2 - q_1) - AV_c$

during compression $Q_d = H_3 - Q_0 + AW_d$.

In the equation for Q_c $M q_c$ represents the heat carried away in the steam condensed at c° temperature by a surface condenser. The term $G(q_2 - q_1)$ is the heat abstracted by the condensing water entering at a temperature e° and leaving at b°.

In the above equations when positive values are obtained for the interchanges, heat is lost by the steam. The sum of interchanges gives the total loss by radiation.

The total radiation can also be determined by the fact that the difference between the heat admitted

and exhausted, less the work must equal the loss. That is

$$D = Q - Mq_c - G(q_t - q_e) - AW$$

Also the total loss must equal the sum of partial losses

$$D_1 = Q_a + Q_b + Q_c + Q_d$$

Such are the thermodynamical equations and theory of the test. We now give the actual manner of conducting the test;—

The engine was run with a constant load on the prony brake and indicator cards were taken at frequent intervals during the run. The quality of the entering steam was determined by the calorimeter. The weight of steam consumed was ascertained by condensing the exhaust steam and then weighing it. The quantity of condensing water used

was found by running it into a calibrated cistern and taking hook gauge readings of the water level at the beginning and end of the run. The times of all readings during the test were carefully noted.

With the data thus furnished the analysis can be fully entered into. Appended is the detailed calculation of the various quantities for the test of May 1, 1897;-

The first quantity determined was the x of the entering steam. From the log of the test the mean pressure was 96 lbs. by gauge, 96.5 lbs corrected.

The height of the barometer was 29.800 inches

$\therefore$ atmospheric pressure $= .434 \times \frac{29.8}{12} \times 13.59$

$= 14.6$ lbs.

$\therefore$ absolute pressure $= 96.5 + 14.6 = 111.1$ lbs.

The average temperature on the high side of the orifice is 330.75° F. From the tables it is seen that the temperature for 111.1 lbs. is 335.30°.

The difference between the actual temperature and that which it should have been is caused by radiation

$\therefore$ 335.30 − 330.75 = 4.55° radiation

The radiation below the orifice will be practically the same as above it and therefore its average temperature should be increased by the radiation.

$\therefore$ temperature on low side = 285.5 + 4.55

= 290.05°

Then since the energy on the high side must equal that on the low side

$$q_{111.1\#} + x r_{111.1\#} = \lambda_{14.6\#} + c_p (t_2 - t_{14.6\#}).$$

$$306.07 + x \times 878.25 = 1145.91 + .48 (290.05 - 211.65)$$

Solving for x

$$x = \frac{1145.91 + 37.63 - 306.07}{878.25}$$

$$= \frac{877.47}{878.25}$$

$$= .99175$$

This gives the quality of the steam passing through the orifice. But a portion of the moisture has been previously separated. Call the weight of water separated per hour W_s and call the weight of the mixed fluid passing through the orifice per hour W_t and the x as determined above x_t. Then if x represent the percentage of steam in the mixture of steam and water in the supply pipe, the percentage of moisture is

$$1 - x = \frac{W_s + W_t(1 - x_t)}{W_s + W_t}$$

The weight of separated water was $34\frac{1}{2}$ oz. in 1 hr. 17 min. 35 sec.

$W_s = 1.64$

The weight of the mixed fluid passing through the throttling orifice is 104 lbs. 15 $\frac{5}{8}$ oz. in 1 hr. 30 min. Then

$W_t = 69.984$

Substituting in the formula

$$1 - x = \frac{1.64 + 69.984\ (1 - .99175)}{1.64 + 69.984}$$

$$1 - x = .03445$$

$$x = .96555$$

The calculations which follow are only for the head end of the cylinder.

The steam consumed and the condensing water necessary to condense it are divided between the head and crank in proportion to the sum of the clearance and cut off percentages. From the table giving the lengths of cards

the percentage of cut off at head end is .1322 and at crank end .15209. From the log of data and results the percentage of clearance at head end is .0651 and at crank end .059

$$.1322 + .0651 = .1973$$

$$.15209 + .0590 = .21109$$

$$.4084$$

Therefore the proportional part that goes to the head end is

$$\frac{1973}{4084} = .48301$$

During the run there were 1138 lbs of steam condensed in 91 minutes.

$$\therefore \text{wt of steam per hr.} = \frac{1138 \times 60}{91}$$

$$= 750.33 \text{ lbs.}$$

All the quantities which are here calculated are for 100 strokes at each end of the cylinder.

The engine makes 53774 revolutions in 1hr. 30 min.

$$\therefore \text{revolutions per hr.} = \frac{53774 \times 60}{90} = 3582.6$$

$$\text{revolutions per min.} = \frac{3582.6}{60} = 59.71.$$

$$\text{Weight of steam per 100 strokes} = \frac{.48301 \times 750.33 \times 100}{3582.6}$$

$$= 10.118 \text{ lbs.}$$

The volume of the clearance in cubic feet, is

$$V_0 = \frac{126.647}{1728} = .07329$$

The volume of stroke up to Cut off is

$$V_1 = \frac{1945}{1728} \times .13215 = .14876$$

The volume of stroke up to Release (= total volume swept through by Piston

$$V_2 = \frac{1945}{1728} \times 1.0000 = 1.12571$$

The volume of stroke up to beginning of Compression

$$V_3 = \frac{1945}{1728} \times .052859 = .059503$$

The weight of dry steam in the clearance is

$$M_0 = (\bar{V}_0 + \bar{V}_3)\gamma_3 \times 100$$

$$= (.07329 + .059503) \times .04187 \times 100$$

$$= .5560 \text{ lbs.}$$

The readings of the hook-gauge were 33.45 and −.15

33.45 corresponds to 26 cu. ft.

0.0 " " 606 " "

Difference = 580 " "

The weight of one cubic foot of water at the temperature 101° F. is 62.05 lbs.

62.05 × 580 = 359.90. lbs.

To this must be added 144 lbs. which is the quantity necessary to bring the level from 0.0 to −.15.

35990 + 144 = 36134 lbs.

But there was run into the cistern condensed steam weighing 736 lbs. Besides this a large tank full of water

had been sunk in the cistern since its calibration.

The circumference of this tank was 9ft. $7\frac{1}{4}$ in. or 115.25 inches. Therefore the weight of water which it displaces is

$$\frac{62.05 \times 115.25 \times 115.25 (33.45 + .15)}{4 \times 3.1416 \times 1728} = 1275 \text{ lbs.}$$

∴ total weight of condensing water is

$$36134 - 736 - 1275 = 34123 \text{ lbs.}$$

The time between the readings of the hook gauge was

11 hrs. 48 min. 0 sec. − 10 hrs. 11 min. 45 sec. =

= 1 hr. 36 min. 15 sec. =

= 96.25 min.

weight of condensing water per hr. $= \frac{34123 \times 60}{96.25}$

$= 21267$ lbs.

weight of condensing water per 100 strokes $= C = \frac{.48301 \times 21267 \times 100}{3582.6}$

$= 286.4$

The heat given to the condensing water is

$$K = G\left(q_{111.3^\circ} - q_{76.7^\circ}\right) = 286.4(79.3 - 45.2)$$

$$= 286.4 \times 34.1$$

$$= 9781 \text{ heat units}$$

There is heat radiated from the condenser. The total area is 4082 sq in. The radiation per sq ft per hr. per degree difference of temperature between the surface and the surrounding air, is given by Carpenter as .648 heat units. Therefore the radiation from condenser is

$$K_1 = \frac{\cdot 48301 \times 100}{3582.6} \times .648 \times \frac{4082}{144}\left(217.88^\circ - 78^\circ\right)$$

in which the two temperatures are respectively temperature of exhaust steam and room.

$$K_1 = 34.65$$

The heat supplied to the engine is

$$Q = M\,(q_{109.7^{\#}} + x\,r_{109.7^{\#}})$$

$$= 10.118\,(305.0 + .96555 \times 879)$$

$$= 11673.2 \text{ heat units.}$$

The heat retained by compression is

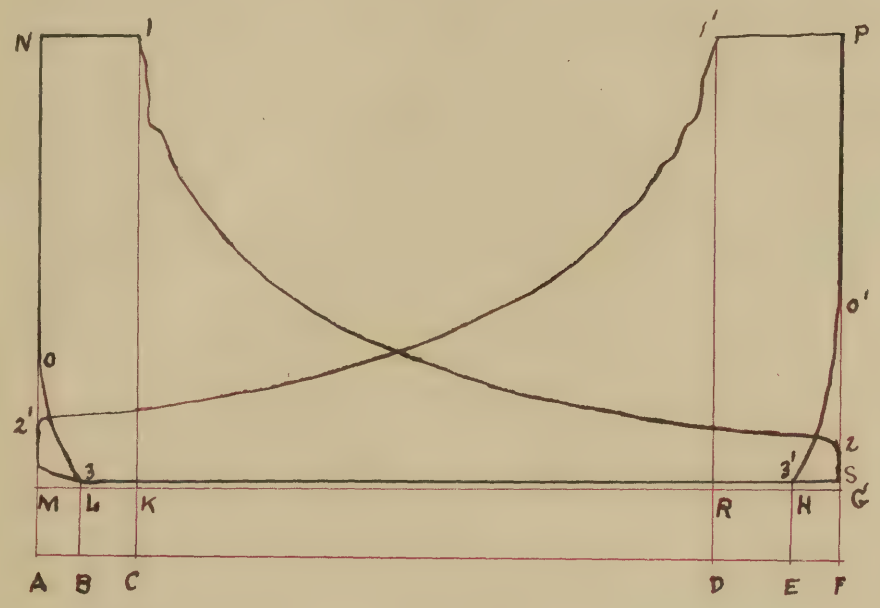
$$Q_0 = M_0\,(q_{46^{\#}} + \rho_{46^{\#}})$$

$$= .556\,(245.0 + 843.7)$$

$$= 605.31$$

As shown in the log, indicator cards were taken at frequent intervals. Below the atmospheric line was drawn a parallel line for perfect vacuum at ~~at~~ a distance below it equal to the atmospheric pressure as determined by the barometer reading. Normals were then dropped from the points of

cut off, release, compression, and admission upon this line. Then the area NICAN



is proportional to the work of admission; area 1 2 F C to the work of expansion; area S F B 3 to the work of exhaust; and the area 0 3 B A is proportional to the work of compression.

The card on the left was obtained from the head end while that on right was from the crank end. To find the work done under the different

events of the stroke multiply the area of that portion of the card measured to the line of perfect vacuum by the area of the piston by pressure scale of the indicator springs by the stroke of the engine (in feet), by 100 and divide by the length of the card ~~multiplied by 12. The 12 is introduced to change the inches, in which all the terms were given, to feet~~.

The indicator spring was 40# to the inch, as determined by calibration.

The stroke was 24 inches and the average length the cards was 4.162 inches.

The piston area was 81.04 sq. in.

The areas should therefore be multiplied by the constant

$$K = 81.04 \times 40 \times \frac{24}{4.162 \times 12} \times 100$$

Therefore for the different events

the work is;-

under admission = $W_a = 1.503 \times K = 233674$ ft lbs.

" expansion = $W_b = 4.102 \times K = 637750$ " "

" exhaust = $W_c = -1.612 \times K = -250624$ " "

" compression = $W_d = -.143 \times K = -22233$ " "

$W_a + W_b = 233674 + 637750 = 871424$

$W_c + W_d = (250624 + 22233) = -272857$

$W = W_a + W_b + (W_c + W_d) = 871424 - 272857$

$= 598567$ ft lbs.

The heat units under the different events of the stroke are;-

under admission = $AW_a = \frac{233674}{778} = 300.4$

" expansion = $AW_b = \frac{637750}{778} = 819.7$

" exhaust = $AW_c = \frac{-250.624}{778} = -322.1$

" compression = $AW_d = \frac{-22233}{778} = -28.6$

$AW = \frac{598567}{778} = 769.36$

Heat in steam at cut off ;-

first find x_1.

$$x_1 = \frac{(V_0 + V_1) \times 100}{(M + M_0) u_1} - \frac{\sigma}{u_1}$$

$$= \frac{\cdot 22205 \times 100}{(10.118 + \cdot 356)(4.036 + \cdot 016)} - \frac{\cdot 016}{4.036 + \cdot 016}$$

$$= \cdot 51748 - \cdot 00398 = \cdot 51350$$

$$H_1 = (M + M_0)(q_{109.7^\#} + x_1 \rho_{109.7^\#})$$

$$= 10674 (305 + \cdot 5135 \times 797.3)$$

$$= 7625.3$$

Cylinder loss admission =

$$Q_a = Q + Q_0 - H_1 - AW_a$$

$$= 11673.2 + 605.3 - 7625.3 - 300.4$$

$$= 4352.8$$

Heat in steam at release ;-

first find x_2.

$$x_2 = \frac{V_0 + V_2 \times 100}{(M + M_0) u_2} - \frac{\sigma}{u_2}$$

$$x_2 = \frac{1.199 \times 100}{10.674 \times (14.740 - .016)} - \frac{.016}{14.740 - .016}$$

$$= .7629 - .00109 = .76181$$

$$H_2 = (M + M_0)(q_{27.5\#} + x_2 \rho_{27.5})$$

$$= 10.674\ (214.4 + .76181 \times 867.5)$$

$$= 9341.8$$

Cylinder loss expansion

$$Q_b = H_1 - H_2 - AW_f$$

$$= 7625.3 - 9341.8 - 819.7$$

$$= -2536.2$$

Heat at compression

$$H_3 = M_0 (q_{16.5} + \rho_{16.5})$$

$$= .556\ (186.7 + 888.8)$$

$$= 598.0$$

Cylinder loss exhaust ;-

first find the heat carried away

in the condensed steam = $M q_{118.5}$

$= 10 \cdot 118 \times 86.5^{-}$

$= 875.2$

Cylinder loss during exhaust

$Q_c = H_2 - H_3 - M q_c - G(q_e - q_e) - K_1 + A W_c$

$= 9341.8 - 598.0 - 875.2 - 9781.2 - 34.6 + 322.1$

$= -1625.1$

Heat at admission =

$M_0 (q_{46} + \rho_{46}) = 605.3 = Q_0$

same as heat retained by compression

Cylinder loss compression

$Q_d = H_3 - Q_0 + A W_d$

$= 598 - 605.3 + 28.6$

$= 21.3$

Total loss radiation =

$$D_1 = Q_a + Q_b + Q_c + Q_d$$

$$= 4352.8 - 2536.2 - 1625.1 + 21.3$$

$$= 212.8.$$

$$D = Q - M_{q_c} - G(q_l - q_c) - AVV - K_1$$

$$= 11673.2 - 875.2 - 9781.2 - 769.4 - 34.6$$

$$= 212.8.$$

Percentage lost admission :-

$$a = \frac{Q_a}{Q} = \frac{4352.8}{11673.2} = .37289$$

Percentage restored expansion :-

$$b = \frac{Q_b}{Q} = \frac{2536.2}{11673.2} = .2173$$

Percentage restored exhaust :-

$$c = \frac{Q_c}{Q} = \frac{1625.1}{11673.2} = .1392$$

Percentage lost compression

$$d = \frac{Q_d}{Q} = \frac{21.3}{11673.2} = .0018247$$

Percentage of utilized work

$$w = \frac{769.4}{11673.2} = .0659$$

Percentage lost, radiation

$$r = \frac{212.8}{11673.2} = .01823$$

Ratio of radiation to work

$$\frac{D}{AW} = \frac{212.8}{769.4} = .27658$$

Ratio of cylinder condensation to work

$$\frac{Q_a}{AW} = 5.657$$

Carnot efficiency

$$E = \frac{t_1 - t_3}{t_1 + 460.7} = \frac{334.29 - 217.88}{334.29 + 460.7} = \frac{116.41}{794.99}$$

$$= .14643$$

Thermodynamical efficiency

$$E_1 = \frac{AW}{Q} = .0659$$

Ratio of thermodynamical to Carnot efficiency or the efficiency compared with perf engine.

$$E' = \frac{E_1}{E} = \frac{.0659}{.14643} = .45012$$

Indicated Horse Power

I.H.P. Head $= 3.857 \times 40 \times \frac{24}{12 \times 4.1615} \times \frac{81.04 \times 59.71}{33000}$

$= 10.87$

I.H.P. Crank $= 4.227 \times 40 \times \frac{24}{12 \times 4.1615} \times \frac{77.898 \times 59.71}{33000}$

$= 11.45$

I.H.P. total $= 10.87 + 11.45 = 22.32$

Weight of steam per IHP per hr

$= \frac{750.33}{22.32} = 33.62$ lbs.

Brake Horse Power;

zero reading for prony brake = 22 lbs.

gross load = 522 "

net load = 500 "

$$\text{Brake H.P.} = 500 \times 86.1 \times 3.1416 \times \frac{3582.6}{60 \times 33000}$$

$$= 20.392$$

Weight of steam per brake horse power

$$= \frac{750.33}{20.392} = 36.79 \text{ lbs.}$$

Mechanical efficiency;-

$$\frac{20.392}{22.32} = .9135$$

Appended are the logs and tables for the two tests of April 9, and May 1, 1897. In the former the reading of the hook gauge was

at beginning 33.6 at 2 hrs. 57 mn. 15 sec.

at end 10.27 " 5 hrs. 13 min. 15 sec.

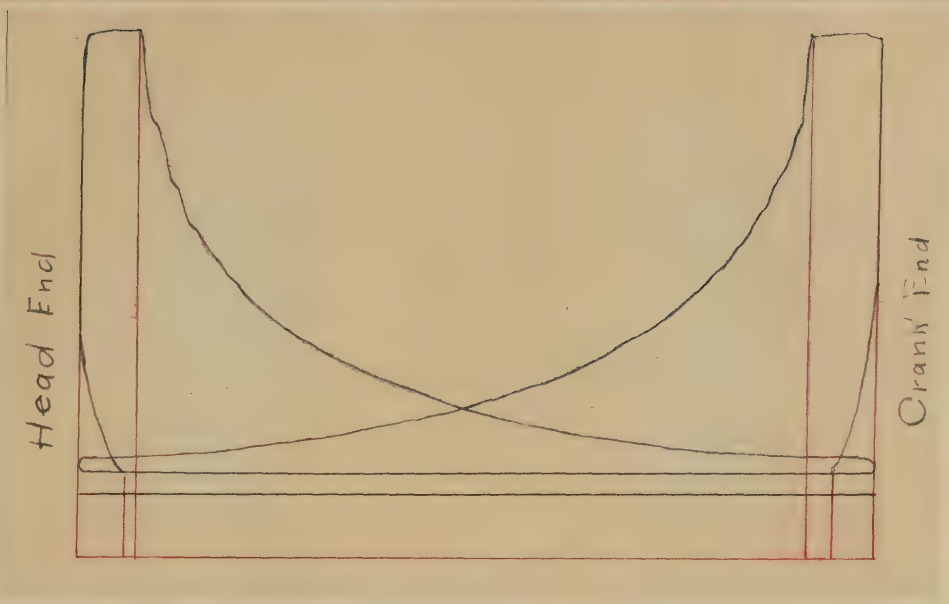
The average net load was 279 lbs., the zero reading of the brake being 75 lbs.

From these results we arrive at the following conclusions;-

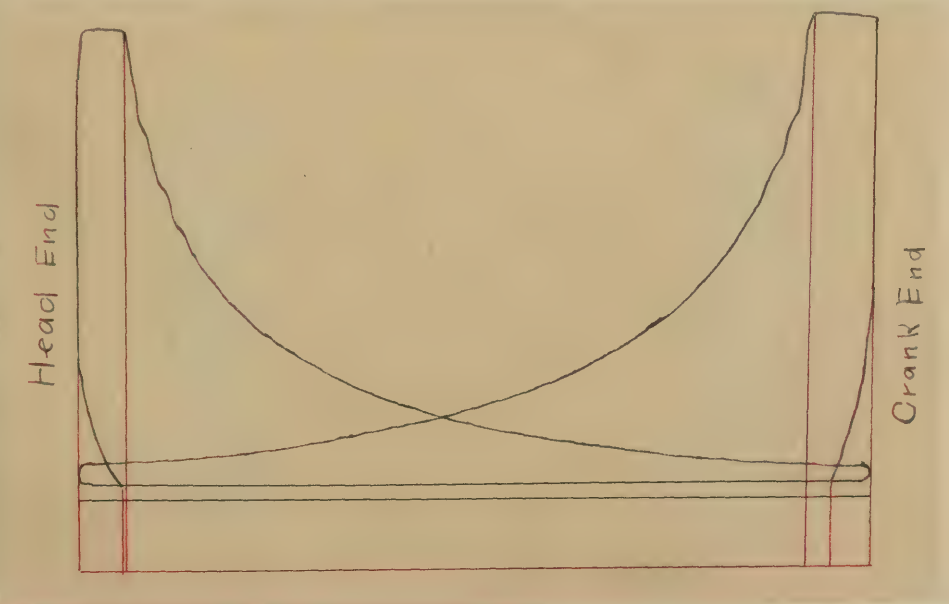
The mechanical efficiency decreases with the load becoming zero at no load.

The steam consumption at the larger load was much more economical than at the smaller load. The saving in steam per brake horse-power was 27.9 per cent. and per I.H.P. 17.2 per cent.

The x at cut off in the 20 H.P. run was considerably higher than in 11 HP test. This also affected the losses during admission and expansion, diminishing the heat lost in the former and the heat restored in the latter.



Date	April-9-1897	Piston Rod	2"
Taken by	G.H.Bromley	Barometer	29.876
Scale	40 lbs. to inch	Engine Constant	.00481
Boiler Pressure	94.9 lbs (Gauge)	Diagram Area Head	2.43 sq. in.
Revolutions	60.9	Diagram Area Crank	2.62 " "
Inj. Water	63.4°	Diag. Length	4.14"
Discharge	118.5°	M.E.P. Head	23.48 lbs
Condensed Steam	108.2°	M.E.P. Crank	25.32 lbs
Piston Diameter	$10\frac{5}{32}$"	I.H.P. Head	7.04
Stroke	24"	I.H.P. Crank	7.26
		I.H.P. Total	14.30



Log of Engine Test - April - 9 - '97

Time	Revolutions	Weight Condensed Steam	Gauge Pressure	Temperature Steam Cooled	Temperature Injection Water	Temperature Discharge Water	Temperature Air Pump Hight	Temperature Air Pump Low	Calorimeter Steam Main	Wt. Pair Empty Separator	Wt. Pail Full Separator	Wt. Bucket Empty Condenser	Wt. Bucket Full Condenser	Time Empty
3.10	9346		96	107	64	108	331	283	3-28-0			5-4-5	24-5-14	3-13-0
3.15	9649		94	104	63	120	330	283		1-0-0	1-5-4	4-5-9	23-12-9	3-31-0
3.20	9968		97	106	63	121	331	283	3-40-30			4-5-10	23-4-10	3-48-0
3.25	0270		94	108	63	123	333	284		0-15-4	1-4-8	4-5-12	23-2-8	4-05-0
3.30	0574		98	109	63	123	333	283	3-52-0			4-5-10	23-0-5	4-22-0
3.35	0878		95	107	63	117	330	284		0-15-3	1-4-4	4-5-11	23-0-7	4-39-0
3.40	1183		95	107	63	118	330	283	4-3-40					4-55-0
3.45	1507	4-4 lbs	93	106	63	118	329	283		0-15-12	1-5-13			
3.50	55303	= 4-3715 lbs	93	106	63	118	330	283	4-16-50					
3.55	55606	= 331 lbs	94	107	64	119	330	283		0-12-12	1-2-7			
4.00	55910		94	106	64	118	330	283	4-28-20					
4.05	56213		90	107	64	119	328	282		0-14-1	1-4-14			
4.10	56576		93	108	64	118	330	282	4-44-30					
4.15	56821		97	109	64	121	332	283		0-15-2	1-5-11			
4.20	57126	Steam 3-45-0	107	111	64	122	334	285	5-0-30					
4.25	57430	Water 4-34-0	100	110	64	120	334	285						
4.30	57735	Steam 5-12-0	100	110	64	119	334	285						
4.35	58040		98	110	64	119	333	285						
4.40	58344	Steam 3-50-0 lbs	96	109	64	116	331	284						
4.45	58649	Water 3-37-0	97	109	64	118	332	284						
4.50	58953	Steam 4-37-0	96	110	63	117	332	284						
4.55	59257		92	110	63	117	329	283						
5.00	59560		92	110	63	119	328	282						
5.05	59863		90	110	63	117	327	282						
Totals	6121	1,215.5 lbs							1-32-30	6-8-2	7-0-13	27-0-9	140-10-7	1-42-0
Means		in 2-5-0	94.4	108.2	63.4	118.5	330.1	283.4						

april-9-'97

Areas of Cards in square inches

Card	Head End					Crank End				
	Admission	Expansion	Exhaust	Compress	Total	Admission	Expansion	Exhaust	Compress	Total
3.10	.87	3.71	1.71	.18	2.67	.98	3.67	1.72	.18	2.74
3.20	.82	3.68	1.84	.19	2.51	1.07	3.64	1.88	.17	2.67
3.30	.86	3.50	1.72	.16	2.44	.95	3.53	1.72	.18	2.61
3.40	.84	3.68	1.86	.16	2.50	.91	3.72	1.89	.17	2.57
3.50	.71	3.50	1.71	.16	2.39	.80	3.50	1.72	.17	2.41
4.00	.78	3.55	1.75	.17	2.41	.87	3.48	1.75	.15	2.46
4.10	.79	3.51	1.76	.16	2.37	.84	3.64	1.80	.17	2.50
4.20	.87	3.73	1.82	.14	2.63	.97	3.72	1.85	.17	2.68
4.30	.70	3.52	1.74	.16	2.32	.98	3.72	1.76	.15	2.79
4.40	.69	3.41	1.70	.18	2.25	.98	3.61	1.78	.16	2.66
4.50	.61	3.54	1.75	.16	2.24	.84	3.67	1.73	.17	2.63
5.00	.78	3.59	1.70	.16	2.50	.82	3.57	1.72	.17	2.50
5.10	.78	3.54	1.75	.16	2.41	1.02	3.68	1.78	.15	2.77
Mean	.777	3.580	1.755	.160	2.431	.925	3.636	1.777	.166	2.618

April-9-'97

Lengths of Cards (inches)

	Head			Crimp	
Card	Cut off	Crimp	Total	Cut off	Crimp
3.10	.34	.24	4.14	.35	.21
3.20	.32	.24	4.15	.38	.20
3.30	.38	.24	4.14	.34	.21
3.40	.30	.22	4.13	.32	.21
3.50	.26	.23	4.15	.30	.21
4.00	.27	.24	4.13	.32	.20
4.10	.30	.22	4.14	.31	.21
4.20	.30	.21	4.13	.34	.20
4.30	.24	.24	4.13	.34	.20
4.40	.25	.23	4.14	.36	.22
4.50	.31	.21	4.16	.28	.22
5.00	.28	.22	4.16	.32	.22
5.10	.30	.22	4.14	.40	.20
Mean	.284	.228	4.142	.335	.208
% Strk	6.86	94.50	—	8.09	95.00

April-9-97

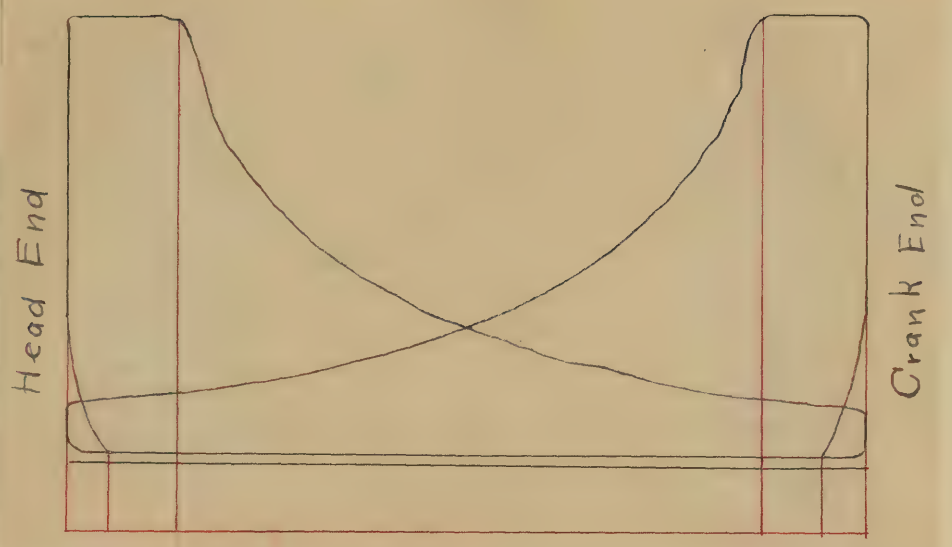
Concrete Pressures

	Head End				Crank End			
Card	Cut off	Release	Beginning of Compression	Admission	Cut off	Release	Beginning of Compression	Admission
3.10	109	23	19	46	110	22	18	57
3.20	109	22	19	50	111	22	19	54
3.30	110	20	17	46	109	21	18	53
3.40	109	23	19	46	110	22	19	49
3.50	106	21	17	45	106	20	17	55
4.00	106	21	18	45	105	21	18	52
4.10	106	21	18	47	108	21	18	53
4.20	102	22	18	44	102	23	19	57
4.30	104	21	18	44	115	22	18	55
4.40	101	20	18	46	110	22	19	49
4.50	101	20	18	47	104	22	18	51
5.00	106	21	18	45	107	21	17	54
5.10	104	22	18	44	106	22	18	51
Mean	106.4	21.3	18.0	45.8	107.2	21.6	18.0	53.1

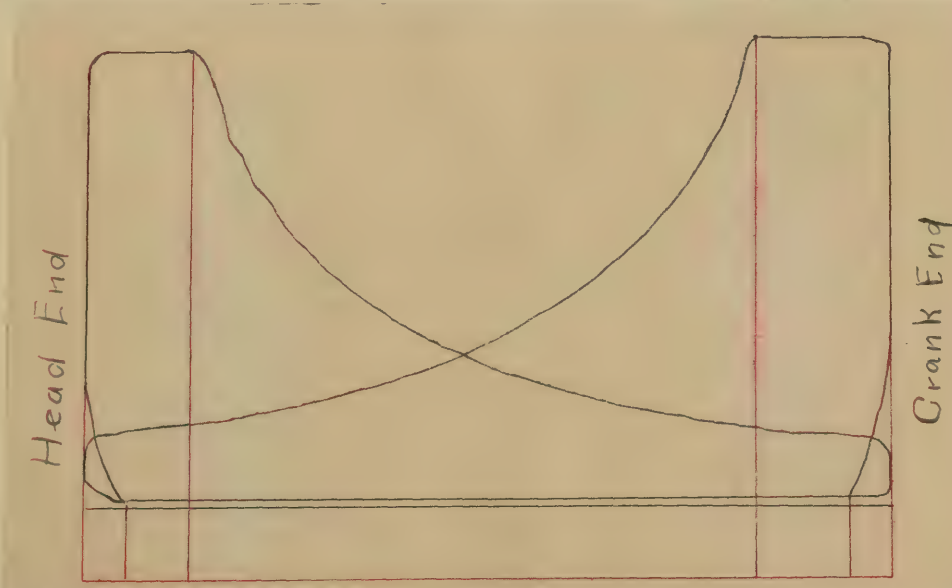
April-9-'97

Absolute Pressures from Indicator Diagrams and Corresponding Properties of Saturated Steam.

		Cut off	Release	Beginning of Compression	Beginning of Admission	Peabody Symbols
Absolute Pressures	Head	106.4	21.3	18.0	45.8	p
	Crank	107.2	21.6	18.0	53.1	
Heat of Liquid	Head	302.6	200.2	191.3	244.7	q
	Crank	303.2	201.0	191.3	254.1	
Internal Latent Heat	Head	799.1	878.4	885.3	843.9	ρ
	Crank	798.8	877.8	885.3	836.7	
Latent Heat of Vaporization	Head	880.6	952.3	958.5	921.2	r
	Crank	880.3	951.7	958.5	914.7	
Total Heat	Head	1183.2	1152.5	1149.8	1165.9	λ
	Crank	1183.4	1152.7	1149.8	1168.7	
Vol. one lb in cu. ft.	Head	4.154	18.77	22.00	9.134	S
	Crank	4.125	18.52	22.00	7.953	
Volume (cu. ft.)	Head end	.15745	1.1990	.1392	.07329	
	Crank end	.15137	1.1449	.1182	.06386	
Volumes Symbols		$V_0 + V_1$	$V_0 + V_2$	$V_0 + V_3$	V_0	



Date	May-1-1897	Piston Rod	2"
Taken by	J.R. Galbraith	Barometer	29.800
Scale	40 lbs. to inch	Engine Constant	.00481
Boiler Pressure	96.5 lbs. (Gauge)	Diagram Area	Head – 3.35 sq in.
Revolutions	59.7		Crank – 4.21 "
Inj. Water	76.7°	Diag. Length	4 1/6"
Discharge	111.3°	M.E.P. Head	37.02 lbs
Condensed Steam	118.5°	Crank	40.48 lbs.
Piston Diam	$10\frac{5}{32}$"	I.H.P. Head	10.87
Stroke	24"	Crank	11.45
		Total	22.32



Log of Engine Test - May-1-'97.

Time	Revolutions	Weight Condensed Steam	Gauge Pressure	Condens. Steam	Temp. Injection water	Temp. Discharge water	Temp. Engine Room	Temp. Boiler Room	Time at mark	Calorimeter Wt. Pail empty	Calorimeter Wt. Pail full	Wt. Bucket Empty	Wt. Bucket Full	Time Empty
										Separator		Condenser		
10-15	7242	178	101	117	75	110	334	288	10-11-15	2-2-13	2-10-8	5-3-14	2H5 8	10-30-0
10-20	7539	243	99	117	75	110	332	287	10-27-0			5-3-14	20-9-1	10-46-0
10-25	7836	305	98	117	75	110	332	285	11-3-30	2-2-10	2-7-11	5-3-14	19-6-6	11-0-0
10-30	8134	368	97	117	75	110	333	287	11-15-30	2-3-3	2-11-3	5-3-14	25-0-3	11-13-0
10-35	8431	427	95	117	75	110	331	286	11-31-30	2-1-1	2-10-2	5-3-14	24-15-12	11-29-0
10-40	8729	491	98	117	76	110	332	286	11-55-30	2-3-7	2-7-13	5-3-14	24-8-0	11-45-0
10-45	9028	554	95	117	76	111	330	285	12-5-20					12-0-0
10-50	9326	618/379	94	118	76	111	329	285						
10-55	9625	442	94	118	77	111	329	285						
11-00	9923	503	94	119	77	112	329	285						
11-05	0222	565	93	119	77	112	329	284						
11-10	0529	629	94	119	77	112	329	285						
11-15	0820	692	95	120	78	111	330	285						
11-19	1120	195	96	120	78	112	330	283						
11-26	1479	281	96	120	78	113	331	284						
11-30	1718	331	96	120	78	112	331	286						
11-35	2016	395	94	121	78	113	330	285						
11-40	2316	456	96	121	78	112	331	286						
11-45	2616	517	95	120	78	112	332	286						
Totals	5374	1075							1-17-35	10-13-2	12-15-10	31-7-1	136-6-14	1-10-0
Means			96.0	118.5	76.7	111.5	330.15	285.5						

May-1-'97

Areas of Cards (sq. in)

	Head End					Crank End				
Card	Admission	Expansion	Exhaust	Compression	Total	Admission	Expansion	Exhaust	Compression	Total
10.25	1.56	4.21	1.62	.14	4.01	1.96	4.33	1.60	.17	4.53
10.40	1.56	4.15	1.61	.15	3.59	1.76	4.30	1.63	.17	4.26
10.55	1.41	3.90	1.56	.16	3.95	1.82	4.18	1.60	.17	4.23
11.10	1.53	4.01	1.54	.13	3.87	1.47	4.14	1.56	.17	3.90
11.25	1.51	4.28	1.70	.14	3.95	1.99	4.26	1.70	.17	4.38
11.40	1.45	4.56	1.64	.14	3.73	1.64	4.10	1.63	.17	3.99
Mean	1.503	4.102	1.613	.143	3.850	1.773	4.227	1.620	.170	4.210

May-1-'97

Length of Cards in inches

Card	Head		Total	Crank	
	Centre	Compass		Centre	Compass
10.25	.66	.22	4.15	.69	.24
10.40	.65	.20	4.15	.63	.22
10.55	.61	.20	4.17	.63	.22
11.10	.58	.21	4.16	.55	.23
11.25	.54	.22	4.17	.70	.21
11.40	.64	.21	4.17	.60	.24
Mean	.550	.220	4.162	.633	.227
1/10 Inch	13.215	94.714		15.209	94.553

May-1-'97

Absolute Pressures

	Head					Crank			
Time	Entry	Release	Beginning Compression	Admission		Entry	Release	Beginning Compression	Admission
10.25	111	27	17	47		111	31	16	47
10.40	111	27	17	49		111	29	16	56
10.55	111	27	17	49		111	29	16	56
11.10	107	27	16	44		108	26	16	47
11.25	110	29	16	44		111	28	17	48
11.40	108	28	16	43		109	27	16	48
Mean	109.1	27.5	16.5	46.0		110.2	28.3	16.2	50.3

May-1-'97

Absolute Pressures from Indicator Diagrams and Corresponding Properties of Saturated Steam

		Cut off	Release	Beginning of compression	Beginning of admission	Peabody Symbols
Absolute Pressure	Head	109.7	27.5	16.5	46.0	p_0
	Crank	110.2	28.3	16.2	50.3	
Heat of Liquid	Head	305.0	214.4	186.7	245.0	q
	Crank	305.3	216.0	185.7	250.6	
Internal Latent Heat	Head	797.3	867.5	888	843.7	p
	Crank	797.0	866.2	889.5	839.4	
Latent Heat of Vaporization	Head	879.0	942.4	961.7	921.0	r
	Crank	878.7	941.3	962.4	917.1	
Total Heat	Head	1184.0	1156.8	1148.4	1166.0	λ
	Crank	1184.0	1157.3	1148.1	1167.7	
Vol. of 1 lb. in cu. ft.	Head	4.036	14.74	23.91	9.097	s
	Crank	4.019	14.35	24.32	8.367	
Volume (Cu. ft.)	Head	.22205	1.199	.13279	.07329	
	Crank	.22841	1.145	.12279	.06386	
Volume Symbols		V_0+V_1	V_0+V_2	V_0+V_3	V_0	

Work per 100 sq Inches (in heat units & ft lbs.)

		April—9-1897				May—1—1897			
		Head		Crank		Head		Crank	
		Ft. lbs	Hu.	Ft. lbs	Hu.	Ft lbs	Hu	Ft lbs	Hu
Admission	a	120800	155.27	138202	177.64	233074	300.1	264965	340.6
Expansion	b	556590	715.40	543370	698.43	637760	819.7	631750	812.0
Exhaust	c	-272808	-350.71	-265550	-341.34	-250624	-322.1	-242106	-311.2
Compression	d	-25602	-32.91	-24837	-31.81	-22233	-28.6	-25406	-32.7
Total		378880	486.99	388136	499.45	598563	769.4	631153	808.7

Data and Results (Boiler)

		April-9	May-1
Condensing water per hour (pounds)		10255	21267
Condensing water per 100 lbs. dry steam	Head	130.2	280.4
" " " "	Crank	144.7	306.9
Temperature condensed steam (°F)		108.25	118.5
Temperature condensing water (°F)		63.45	76.7
" " " (Exit)		118.55	111.2
Revolutions per hour		3652	3582.0
Cut off, (Ratio)	Head	6.86	13.22
" "	Crank	8.28	15.21
Release "	Head	100.00	100.00
" "	Crank	100.00	100.00
Compression "	Head	74.5	94.71
" "	Crank	45.0	94.55
Indicated horse power	Head	7.036	10.87
" " "	Crank	7.266	11.45
" " "	Total	14.302	22.32
Brake horse power		11.43	20.34
Water per I.H.P. Rate (pounds)		10.72	33.02
Water per B.H.P. (pounds)		51.05	35.77
Mechanical efficiency		.7977	.9135

Data and Results

		April-9 1897	May-1
Kind of Engine		Corliss	
Diameter of Cylinder inches		$10\frac{5}{32}$	
Length of Stroke inches		2-1	
Diameter of Piston Rod inches		2	
Area Cylinder Eng't	Head	1.1910	
" "	Crank	1.1458	
Area Clearance Eng't	Head	.0133	
" "	Crank	.0033	
Clearance in Stroke	Head	6.8	
" "	Crank	5.1	
Boiler Pressure Gauge (pounds)		94.7	96.3
" " Absolute "		109.4	111.0
Entering Steam Pressure Absolute (lbs)		106.8	113.0
Duration of Test, hours		2	$1\frac{1}{2}$
Steam used during run, pounds		1167	1125.5
Steam used per hour		5835	750.3
Steam per 100 H Pes	Head	7.750	13.11
" "	Crank	8.226	13.725
Quality of entering Steam (% Steam)		.17434	.96555

Data and Results per 100 strokes

		April—9—97			May—1—97		
		Head	Crank	Total	Head	Crank	Total
Weight of Steam (lbs)	M	7.750	8.226	15.976	10.118	10.825	20.943
Wt. dry Steam in Clearance	M_0	0.6329	0.5374	1.1703	0.5560	0.5053	1.0613
Total weight Steam	$M+M_0$	8.3829	8.7634	17.1463	10.6740	11.3303	22.0043
Wt. condensing water	G	136.2	144.6	280.8	306.9	286.4	593.3
Heat given Cond. Water	K	7489.3	7935.0	15424.3	9781.2	10465.1	20246.3
Heat radiated by Cylinder	K_1	36.6	38.9	75.5	34.6	36.9	71.4
Heat Supplied Engine	Q	8795.0	9549.5	18344.5	11673.2	12445.8	24119.0
Heat retained by Compress	Q_0	688.7	586.2	1274.9	605.3	550.7	1156.0
Heat in Steam at Cut-off	H_1	5551.2	5809.2	11360.4	7625.3	7971.3	15596.6
Cyl. loss during Admission	Q_a	3777.4	4148.9	7926.3	4352.8	4684.6	9037.4
Heat in Steam at Release	H_2	7287.3	7178.2	14465.5	9341.8	9360.5	18702.3
Cyl. Loss during Expansion	Q_b	-2451.4	-2067.4	-4518.8	-2536.2	-2201.2	-4737.4
Heat in Steam at Compression	H_3	681.4	578.6	1260.0	598.0	543.3	1141.3
Heat in Condensed Steam	H_4	590.5	627.2	1217.7	875.2	936.3	1811.5
Cyl. loss during Exhaust	Q_c	-1123.2	-1660.2	-2783.4	-1625.1	-2309.9	-3935.0
Cyl. Loss during Compress	Q_d	25.5	24.2	49.7	21.3	25.3	46.6
Heat discharged as Work	B	8566.8	9104.0	17670.8	11460.4	12247.0	23707.4
Loss	D	228.2	445.5	673.7	212.8	198.7	411.5
Loss	D_1	229.3	445.5	673.8	212.8	198.7	411.5

Results Per 100 Strokes

		April-9-97 Head	April-9-97 Crank	April-9-97 Total	May-1-97 Head	May-1-97 Crank	May-1-97 Total
Total Heat Entering	Q	8795.0	9549.5	18344.5	11678.2	12445.8	24119.0
Total Heat at Cut off	H_1	5551.2	5809.2	11360.4	7625.3	7971.3	15596.6
Total Heat at Release	H_2	7287.3	7178.2	14465.5	9341.8	9360.5	18702.3
Total Heat Exhausted	$K+H_4$	8079.8	8562.2	16642.0	10656.4	11401.4	22057.8
Total Heat at Compression	H_3	681.4	578.6	1260.0	598.0	543.3	1141.3
Total Heat at Admission	Q_0	688.7	586.2	1274.9	605.3	550.7	1156.0
Quality of Entering Steam	x	97.4	34		96.555		
Quality Steam at Cut off	x_1	44.99	41.65		57.35	49.96	
Quality Steam at Release	x_2	76.17	70.41		76.18	70.42	
To lost - Admission	a	42.95	45.92		37.29	37.67	
To restored Expansion	b	27.87	24.13		21.73	17.70	
To restored Exhaust	c	12.77	17.43		13.92	18.58	
To lost - Compression	d	0.29	0.25		0.18	0.20	
To utilized in work	w	5.54	5.29		6.57	6.50	
To lost Radiation	r	2.60	4.67		1.82	1.60	
Ratio Radiation to Work		.4686	.8859		.2766	.2458	
Ratio Cyl. Condensation to Work		7.756	8.721		5.657	5.794	
Carnot's Efficiency	E	.1290	.1389		.1469	.1480	
Thermodynamical Eff.	E_1	.0554	.0527		.0659	.0650	
Ratio Therm to Carnot	E'	.4294	.3791		.4501	.4395	

E378.748 P0S1897.8

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

CAT. NO. 1935 LIBRARY BUREAU

3 1198 03076 5809
N/1198/03076/5809X